

The Activity of the Neighbours of Seyfert Galaxies.

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ABSTRACT

We present a follow-up study on a series of papers concerning the role of close interactions as a possible triggering mechanism of AGN activity. We have already studied the close ($\leq 100 h^{-1}\text{kpc}$) and the large scale ($\leq 1 h^{-1}\text{Mpc}$) environment of a local sample of Sy1, Sy2 and Bright IRAS galaxies (BIRG) and their respective control samples. The results led us to the conclusion that a close encounter appears capable of activating a sequence where a normal galaxy becomes first a starburst, then a Sy2 and finally a Sy1. However, since both galaxies of an interacting pair should be affected, we present here optical spectroscopy and X-ray imaging of 15 and 16 neighbouring galaxies around two samples of 10 Sy1 and 14 Sy2 galaxies respectively. Based on optical spectroscopy, we find that more than 70% of all neighbouring galaxies exhibit starforming and/or nuclear activity (namely enhanced star formation, starbursting and/or AGN), while an additional X-ray analysis showed that this percentage might be significantly higher. Furthermore, we discovered a statistically important trend, at a 99.9% level, regarding the type and strength of the neighbour's activity with respect to the activity of the central galaxy, i.e. that the neighbours of Sy2 galaxies are systematically more ionized than the neighbours of Sy1s, a fact that indicates differences in metallicity, stellar mass and star-formation history between the samples. Our results are consistent with the link between close galaxy interactions and activity and also provide more clues regarding the possible evolutionary sequence inferred by our previous studies.

Key words. Galaxies: Active, Galaxies: Seyfert, Galaxies: Starburst, X-ray: Galaxies, Cosmology: Large-Scale Structure of Universe

1. Introduction

Since the discovery of Active Galactic Nuclei (AGN), significant effort has been put in the attempt to reveal their nature. Nowadays, we are certain that the accretion of material into a centrally located massive black hole (MBH) is responsible for the detected excess emission in the AGN's spectra and such black holes do exist in all elliptical galaxies and spiral galaxy bulges (Kormendy and Richstone 1995; Magorrian et al. 1998), including our own (e.g. Melia & Falcke 2001). However, we still lack a complete understanding of the various aspects of activity, for example the triggering mechanism and the feeding of the black hole, the physical properties of the accretion disk and the obscuring torus predicted by the unified scheme (Antonucci et al. 1993), the origin of jets in radio loud objects, the connection with star formation and the role of the AGN feedback. Even the exact mechanism that produces the observed IR, X-ray, and gamma-ray emission, is still only partially understood. The unification model itself, although successful in many cases, has not been able to fully explain all the AGN phenomenology (among others, the role of interactions on induced activity; Koulouridis et al. 2006a,b and references therein).

The lack of detailed knowledge of key aspects of the AGN mechanism leaves us with many scattered pieces of information. Theory is unable in most cases to explain observations, and observations still cannot clearly resolve the galactic nuclei to confirm theories. Radio-loud and radio-quiet AGN, QSO type I and II, Sy1 and Sy2 galaxies, LINERs, transition galaxies between different states (TOs) and starburst galaxies, are some of the pieces of the puzzle that we are called to unify. Examination of the properties of the host galaxies of the different types of

AGN and their environment up to several hundred kpc, can give us valuable information on the nature of the general AGN population as well as on different properties of each AGN subtype. In addition, the availability nowadays of large, automatically constructed, galaxy catalogues, like the SDSS, can provide the necessary statistical significance for these type of analyses. However, great caution should be taken when interpreting results based on large databases, since the larger the sample size the less control usually one has on the spectral and other details of the individual galaxy entries. It could then be difficult to attempt to address important questions, such as : Do the Unification paradigm explains all cases of type 1 and type 2 AGN? Which is the true connection between galaxy interactions, star formation and nuclear activity? What is the lifetime of these phenomena? How do LINERs fit in the general picture and can all be considered AGN? Do evolutionary trends affect the AGN phenomenology? etc.

1.1. Triggering an AGN evolutionary sequence?

Despite observational difficulties and limitations, there have been many attempts, based on different diagnostics, to investigate the possible triggering mechanisms of nuclear activity. Most agree that the accretion of material into a MBH (Lynden-Bell 1969) is the mechanism responsible for the emission, but it is still necessary to understand the feeding mechanism of the black hole. It is known and widely accepted that interactions between galaxies can drive gas and molecular clouds towards their nucleus initiating an enhanced star formation (e.g. Li et al. 2008; Ellison et al. 2008; Ideue et al. 2012). Many also believe

that the same mechanism could give birth to an active nucleus (e.g. Umemura 1998; Kawakatu et al. 2006; Ellison et al. 2011; Silverman et al. 2011).

Indeed, there are several studies that conclude that there is an evolutionary sequence from starburst to Seyfert galaxies (e.g. Storchi-Bergmann et al. 2001). Based on the number and proximity of close ($\lesssim 60 - 100 h^{-1}\text{kpc}$) neighbours around different types of active (Sy1, Sy2 and BIRG) galaxies (e.g. Dultzin-Hacyan et al. 1999; Krongold et al. 2002; Koulouridis et al. 2006a,b) a very interesting evolutionary sequence has been suggested, starting with a close interaction that triggers the formation of a nuclear starburst, subsequently evolving to a type 2 Seyfert, and finally to a Sy1. This sequence is likely independent of luminosity, as similar trends have been proposed for LINERs (Krongold et al. 2003) and ULIRGs and Quasars (Fiore et al. 2008 and references therein). Furthermore, numerical simulations by Hopkins et al. (2008) outlined such an evolutionary scheme for merging galaxies. The proposed activity evolution can fully explain the excess of starbursts and type 2 AGN in interacting systems, as well as the lack of type 1 AGN in compact groups of galaxies (Martínez et al. 2008) and galaxy pairs (e.g. Gonzalez et al. 2008).

In addition, post starburst stellar populations have been observed around AGN (Dultzin-Hacyan & Benitez 1994; Maiolino & Rieke 1995; Nelson & Whittle 1996; Hunt et al. 1997; Maiolino et al. 1997; Cid Fernandes, Storchi-Bergmann & Schmitt 1998; Boisson et al. 2000, 2004; Cid Fernandes et al. 2001, 2004, 2005) and in close proximity to the core (~ 50 pc). This fact implies the continuity of these two states and a delay of 0.05-0.25 Gyr between the onset of the starburst and the lighting up of the AGN (Müller Sánchez et al. 2008; Wild, Heckman, & Charlot 2010; Davies et al. 2012), which may reach the peak of its activity after 0.5-0.7 Gyr (Kaviraj et al. 2008, 2011). Davies et al. (2007), analyzing star formation in the nuclei of nine Seyfert galaxies found recent, but no longer active, starbursts which occurred 10 - 300 Myr ago. Furthermore, most of these studies (e.g. Hunt et al. 1997; Maiolino et al. 1997, Gu et al. 2001) separate type I from type II objects implying that recent star-formation is only present in type II objects (see also Coldwell et al. 2009). Support for an interaction-activity relation was recently provided by HI observations of Tang et al. (2008), who found that 94% of Seyfert galaxies in their sample were disturbed in contrast to their control sample (where only 19% were disturbed), but see also Georgakakis et al. (2009) and Cisternas et al. (2011) in the AEGIS and cosmos surveys respectively. We point out that a great theoretical success of the starburst/AGN connection is the quenching of the induced star formation by the AGN feedback, which can explain the formation of red and dead elliptical galaxies (e.g. Springel et al. 2005a; Di Matteo et al. 2005; Khalatyan et al. 2008). Recent observational studies and simulations have shown that AGN ionized outflows may carry enough energy to cease star formation in the host galaxy (e.g. Krongold et al. 2007, 2009; Blustin et al. 2008; Hopkins & Elvis 2010; Novak, Ostriker & Ciotti 2011; Cano-Díaz et al. 2012; Zubovas & King 2012). In addition, the correlation of morphologies of the host galaxies with the nuclear activity type can also lead us to a possible AGN evolutionary sequence (Martínez et al. 2008).

We stress that the proposed evolutionary scenario does not invalidate the unification scheme. It implies that the orientation of the torus can determine the AGN phenomenology only at specific phases of the evolutionary sequence. In particular, this probably occurs when the obscuring molecular clouds form the torus, before being completely swept away.

1.2. This work

This paper is the third in a series of 3-dimensional studies of the environment of active galaxies (Koulouridis et al. 2006a,b), extending previous 2D analyses (Dultzin et al. 1999, Krongold et al. 2002), in an effort to shed more light to the starburst/AGN connection and to the evolutionary scenario proposed in our previous papers. It is a follow-up spectroscopic study aiming at investigating the possible effects of interactions on the neighbours of our Seyfert galaxies and understanding the conditions necessary for the different types of activity.

In §2 we will discuss our galaxy samples and we will present our observations and data reduction. The spectroscopic analysis and classification of the galaxies and the analysis of the available X-ray observations is presented in section §3. Finally, in section §4 we will interpret our results and draw our conclusions. Due to the fact that all our samples are local, cosmological corrections of galaxy distances are negligible. Throughout our paper we use $H_0 = 100 h^{-1}$ Mpc. Note that we use the term “active” for all galaxies that exhibit emission lines in their spectra, their origin being either nuclear activity and/or star-formation.

2. Data

2.1. Sample Definition and Previous Results

The samples of active galaxies were initially compiled from the catalogue of Lipovetskyj, Neisvestnyj & Neisvetnaya (1987). The original catalogue itself is a compilation of all Seyfert galaxies known at the time from various surveys and in various frequencies (optical, X-ray, radio, infrared). It includes all extended objects and several starlike objects with absolute magnitudes lower than -24. Multifrequency data are compiled and listed, including : coordinates, redshifts, Seyfert type (and sub-type), UBVR-photoelectric magnitudes, morphological types, fluxes in H_β and [OIII]5007, JHKLN fluxes, far-IR (IRAS) fluxes, radio fluxes at 6 and 11 cm, monochromatic X-Ray fluxes in 0.3 - 3.5 and 2 - 10 keV. All data can be found online at vizier database (<http://vizier.cfa.harvard.edu/viz-bin/VizieR?-source=VII/173>). About half of the listed Seyfert galaxies can also be found in the IRAS catalogue and thus are IR selected.

Dultzin-Hacyan et al. (1999) selected from the catalogue two volume limited and complete samples, consisting of 72 Sy1 and 60 Sy2, to study their circumgalactic environment. In Koulouridis et al. (2006a), we used the same samples in order to verify their results, using in addition redshift data from the CFA2 and SSRS surveys and our own deeper spectroscopic observations. Our samples were limited in the area of these two surveys (48 Sy1 and 56 Sy2) but were tested for consistency with the original ones. In both studies, well selected control samples (same redshift, diameter and morphology distributions) were used for the comparison.

Using the CfA2 and SSRS redshift catalogues, we searched for neighbours within a projected distance $D \leq 100 h^{-1}$ kpc and a radial velocity separation $\delta u \leq 600\text{km/sec}$ and we found that:

- The Sy1 galaxies and their control sample show a similar (consistent within 1σ Poisson uncertainty) fraction of objects having at least one close neighbour.
- There is a significantly higher fraction of Sy2 galaxies having a near neighbour, especially within $D \leq 75 h^{-1}$ kpc, with respect to both their control sample and the Sy1 galaxies.

- The large-scale environment of Sy1 galaxies ($D = 1 h^{-1}$ Mpc and $\delta u \leq 1000$ km/sec) is denser than that of Sy2 galaxies, although consistent with their respective control samples.

In order to investigate whether fainter neighbours, than those found in the relatively shallow CFA2 and SSRS catalogues, exist around our AGN samples, we obtained our own spectroscopic observations of all neighbours with $m_B \lesssim 18.5$ and $D \leq 75 h^{-1}$ kpc for a random subsample of 22 Sy1 and 22 Sy2 galaxies. We found that the percentage of both Sy1 and Sy2 galaxies that have a close neighbour increases correspondingly by about 100% when we descent from $m_B \lesssim 15.5$ to $m_B \lesssim 18.5$. These results imply that the originally found difference between Sy1 and Sy2 persists even when adding fainter neighbours down to $\delta m \lesssim 3$, which correspond to a magnitude similar to the Large Magellanic Cloud.

For the purposes of the present study we analyzed spectra of all the neighbours around the aforementioned subsamples of the 22 Sy1 & 22 Sy2 respectively. In Table 1 and 2 we present the names, celestial coordinates, O_{MAPS} magnitudes¹ and redshifts of the Sy1 and Sy2 galaxies which have at least one close neighbour (within $\delta u < 600$ km/sec). Note that we have kept the original neighbours enumeration of the previous papers (for example, in table 2, NGC1358 has only neighbour 2, since 1 had $\delta u > 600$ km/sec).

2.2. Spectroscopic Observations

We have obtained spectroscopic data of all the neighbour galaxies in our samples in order to classify their type of activity. Optical spectra were taken with the Boller & Chivens spectrograph mounted on the 2.1m telescope at the Observatorio Astronómico Nacional in San Pedro Mártir (OAN-SPM). Observations were carried out during photometric conditions. All spectra were obtained with a 2".5 slit. The typical wavelength range was 4000-8000 Å and the spectral resolution $R=8\text{Å}$. Spectrophotometric standard stars were observed every night.

The data reduction was carried out with the IRAF² package following a standard procedure. Spectra were bias-subtracted and corrected with dome flat-field frames. Arc-lamp (CuHeNeAr) exposures were used for wavelength calibration. All spectra can be found at the end of the paper (Fig.3).

2.3. Analysis and Classification Method

In this section we present results of our spectroscopic observations of all the neighbours with $D \leq 100 h^{-1}$ kpc and $m_{O_{MAPS}} \lesssim 18.5$ for the samples of Sy1 and Sy2 galaxies. We have also used SDSS spectra when available.

Our aim was to measure six emission lines: H_β $\lambda 4861$, H_α $\lambda 6563$, [NII] $\lambda 6583$, [OIII] $\lambda 5007$, [SII] $\lambda 6716$ and [SII] $\lambda 6731$, in order to classify our galaxies, using the Baldwin, Phillips & Terlevich (1981, hereafter BPT) diagrams. Note that it was not possible to measure the H_β and [OIII] emission lines in ESO 545-G013 N1 and thus we classified it using only [NII] and H_α (Stasińska et al. 2006).

¹ O (blue) POSS I plate magnitudes of the Minnesota Automated Plate Scanner (MAPS) system. We use O_{MAPS} magnitudes because Zwicky magnitudes were not available for the fainter neighbours, and we needed a homogeneous magnitude system for all our objects.

² IRAF is distributed by National Optical Astronomy Observatories operated by the Association of Universities for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

Based on the above, we adopted the following classification scheme:

- galaxies with no emission lines are considered to be normal
- galaxies with emission lines are active, meaning that they exhibit nuclear or/and starforming activity.

Flux ratios for the emission lines mentioned above have been measured after subtracting the host galaxy contamination from each spectrum. We disentangle the spectral contribution of the host galaxy from the observed spectra by using the stellar population synthesis code STARLIGHT³. Spectra processing and fits were carried in the same fashion as described in section 3.1 of León-Tavares et al. (2011). For a detailed description of the STARLIGHT code and its scientific results, we refer to the papers of the SEAGal collaboration (Cid-Fernandes et al. 2005, Mateus et al. 2006; Asari et al. 2007; Cid-Fernandes et al. 2007).

Although it is possible to distinguish between a SFG galaxy and an AGN using only the [NII]/ H_α ratio, we cannot distinguish between a low ionization (LINER) and a high ionization (Seyfert) AGN galaxy. We have also measured [OI] ($\lambda = 6300$) when possible, as an extra indicator of AGN activity. However, the weakness of the line in most cases did not allow further use of it in a separate BPT diagram.

In Fig.1a we plot the line ratios $\log([OIII]/H_\beta)$ versus $\log([NII]/H_\alpha)$ (BPT diagram) for those neighbours of Seyfert galaxies for which we have obtained the full spectrum⁴. We also plot the Kauffmann et al. (2003a) separation line between SFG and AGN galaxies, given by:

$$\log([OIII]/H_\beta) = \frac{0.61}{(\log([NII]/H_\alpha) - 0.05)} + 1.3,$$

and the corresponding one of Kewley et al. (2001):

$$\log([OIII]/H_\beta) = \frac{0.61}{(\log([NII]/H_\alpha) - 0.47)} + 1.19.$$

we also plot in Fig.1b the line ratios $\log([OIII]/H_\beta)$ vs $\log([SII]/H_\alpha)$. Qualitatively, the same results as those presented in Fig.1a are repeated here as well. The dividing line is given by Kewley et al. (2006). However, we do not have the respective line of Kauffmann et al. (2003a), as it is not available in the literature, and thus we cannot separate pure starforming galaxies from composite objects. Since the measurement of the [SII] doublet bears in general greater errors, we will draw our results based on the [NII] forbidden line.

We can now classify our objects in the following categories:

- SFG (Starforming Galaxies): all the objects which are found below the line of Kaufmann et al.
- AGN galaxies: the objects which are found above the line of Kewley et al.
- TOs (transition objects): the ones that are found between the two lines and exhibit characteristics of both an active nucleus and a starburst.

We choose to call all galaxies with prominent emission lines, that do not show AGN activity, SFG galaxies. We do not attempt to divide the starforming galaxies into more subcategories since such a categorization appears to be highly subjective and depends on the applied methodology (e.g. Knapen & James, 2009).

³ <http://starlight.ufsc.br/>

⁴ We have excluded two merging neighbours (UGC7064)

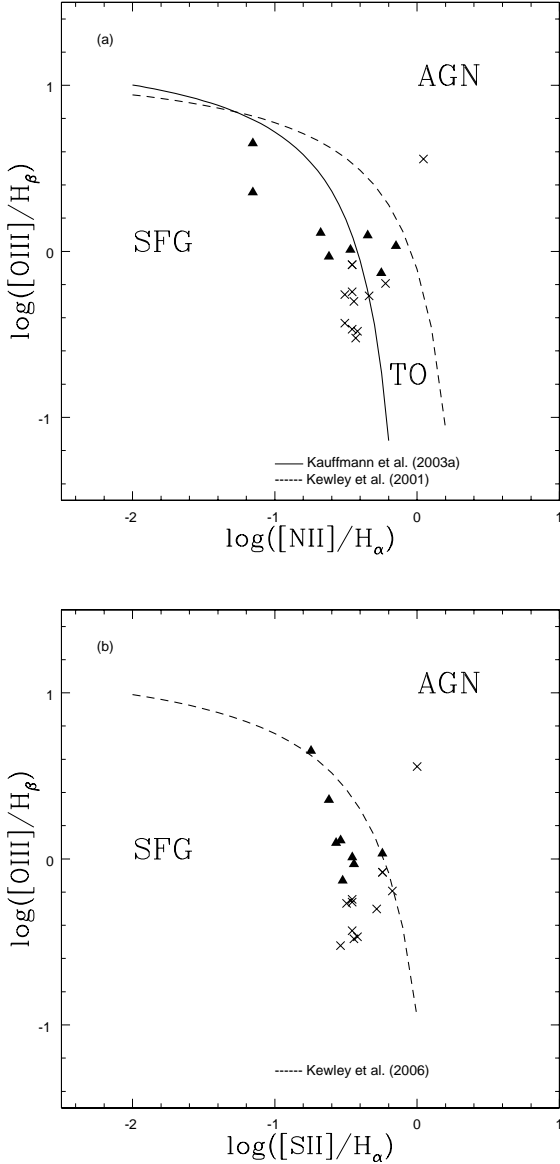


Fig. 1. BPT classification diagrams of the neighbours of Sy1 and Sy2 galaxies. The neighbours of Sy2 and Sy1 galaxies are indicated by triangles and crosses, respectively.

We also classify our objects using only the $[NII]/H\alpha$ ratio, as proposed by Stasińska et al. (2006). In more detail, we classify as AGN those objects with $\log([NII]/H\alpha) > -0.2$, as SFG those with $\log([NII]/H\alpha) < -0.4$, and as TO the rest. We find that it is accurate in all cases, except one (see Table 3), with the only caveat that it cannot distinguish between LINERs and Seyferts. Hence, we use this classification for ESO 545-G013 N1 for which we could not measure the $H\beta$ and $[OIII]$ ($\lambda 5007$) lines.

Further classification of the Seyfert galaxies in type 1 and type 2 was obtained by direct visual examination of the spectra and the broadening of the emission lines. No broad lines were discovered in the spectrum of the two neighbours classified as AGN and therefore they should be considered as type 2. In Table 3 we list for all neighbours their line ratios and the two different classifications. As can be observed, in all cases except NGC3786 N1, the classifications are absolutely consistent.

3. Results and analysis.

3.1. Activity of the neighbours.

In this section we discuss in more detail the results of our spectroscopy and classification. We have excluded from our analysis a Sy2 galaxy with multiple nuclei, since although it qualifies as AGN with a close (merging) neighbour, the individual nuclei are not resolved by our spectroscopy. We have also excluded the merging neighbour of UGC7064, since the properties of its two nuclei are more affected by their mutual interaction than by their neighbouring Seyfert. We can draw our first results for each sample separately inspecting Table 3. From the analyzed 15 neighbours of Sy1 only 4 are normal galaxies, while 8 of them are SFGs, 2 are classified as TOs and one is classified as an AGN. Similar results hold for the neighbours of Sy2 galaxies. 4 out of 13 neighbours do not show activity, 6 are SFGs and 3 are TOs. Therefore, at least 70% of the neighbours, within $100 h^{-1}$ kpc, of both type of Seyfert galaxies are active. We should note here that Ho et al. (1997), studying a magnitude limited sample of galaxies ($B_T \leq 12.5$), came up with a similar high percentage of activity (86%). However, the results of our sample of faint neighbours cannot be directly compared with those of Ho et al. due to the brighter magnitude limit of the latter.

We can extract one of the most interesting results of our analysis by examining Fig.1, i.e. the neighbours of Sy2 galaxies have systematically larger values of $[OIII]/H\beta$ than the neighbours of Sy1 galaxies. Especially for those galaxies that exhibit only star-formation, the ratio $[OIII]/H\alpha$ is mainly an indicator of their ionization level, which in its turn is an indicator of metallicity. Furthermore, metallicity is closely related to the stellar mass ($M_\star - Z_{neb}$ relation). The average age of the stellar population also changes along the $[OIII]/H\beta$ axis, the higher ionized galaxies having higher ratio of current to past star-formation rates (Asari et al. 2007, Cid Fernandes et al. 2009). Summarizing all of the above we conclude that the neighbours of Seyfert 2 galaxies show higher ionization, lower metallicity, less stellar mass and more importantly younger stellar populations than those of Seyfert 1 galaxies. Using a two-dimensional Kolmogorov-Smirnov two-sample test we have verified that the null hypothesis, that the samples are drawn from the same parent population, is rejected at a 99.9% level.

Finally we should note how close to a composite state are the neighbours of active galaxies, in agreement with Kewley et al. (2006a) who showed that the starforming members of close pairs, lie closer to the classification line than the starforming field galaxies. We suggest that galaxies between the curves of Kauffmann et al. (2003) and Kewley et al. (2001) migrate from a pure starforming phase to a pure AGN phase. This suggestion is of great importance to a possible evolutionary scenario and will be discussed further in §4.

Summarizing our main results of this section:

- More than 70% of the neighbours of the two AGN samples exhibit activity, as indicated by optical spectroscopy.
- Around 30% of the neighbors of Sy1 and Sy2 galaxies show the presence of AGN activity.
- The neighbours of Sy2s are systematically more ionized, than the neighbours of Sy1s, indicating that their current to past star formation rate is higher.
- No broad lines (type 1 activity) were detected in the two neighbours which exhibit pure AGN spectra.

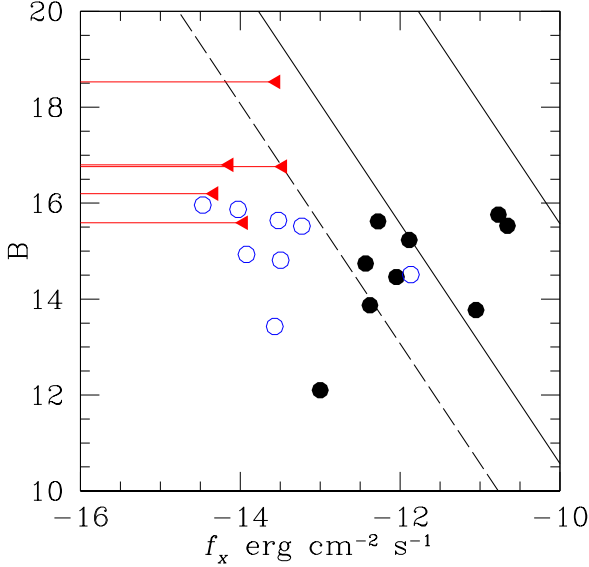


Fig. 2. The X-ray (0.2-12 keV) to optical (B-band) flux diagram for both the AGN targets (solid circles) and the neighbors (open circles). The triangles (upper limits) denote the neighbors with no X-ray detection. The upper, lower solid line and the dash line correspond to $f_X/f_B = +1, -1, -2$ respectively.

3.2. The XMM-Newton observations

We have also explored whether the neighbours show X-ray activity, using the *XMM* public archive. We find that 13 target fields have been observed by *XMM*. However, some of them are very bright and have been observed in partial window mode, rendering the observations in center of the Field-of-View unusable (NGC5548, NGC863, 1H1142-178, NGC7469). The list of the remaining observations (13 neighbours and 9 central Seyfert galaxies) is shown in Table 4, in which we present X-ray fluxes for the detections as well as upper limits for the non-detected sources. The fluxes have been taken from the 2XMM catalogue (Watson et al. 2009). The fluxes refer to the total 0.2-12 keV band for the PN detector or the combined MOS detectors in the case where PN fluxes are not available and are estimated using a photon index of $\Gamma = 1.7$ and an average Galactic column density of $N_H = 3 \times 10^{20} \text{ cm}^{-2}$. Luminosities were estimated using the same spectral parameters. In the same table we quote the 2XMM hardness ratios, derived from the 1-2 keV and 2-4.5 keV bands (hardness ratio-3 according to the 2XMM catalogue notation). The upper limits, derived using the *FLIX* software, are estimated following the method of Carrera et al. (2007). This provides upper-limits to the X-ray flux at a given point in the sky covered by *XMM* pointings. The radius used for deriving the upper limit was 20 or 30 arcsec depending on the presence of contaminating nearby sources.

In Fig.2 we present the X-ray to optical flux diagram $f_X - f_B$ (e.g. Stocke et al. 1991). This diagram provides an idea on whether a galaxy may host an active nucleus. This is because AGN have enhanced X-ray emission at a given optical magnitude relative to normal galaxies. The space usually populated by AGN is shown between the continuous lines. The central Seyfert galaxies are shown as filled points, but since X-ray flux has not been corrected for X-ray absorption, a number of absorbed AGN galaxies lie between the lower and dashed line, while the heavily absorbed Sy2 NGC7743 (Akylas & Georgantopoulos 2009), lie

far below the dashed line. One neighbour which lies in the AGN regime (NGC7682-N1) can be clearly seen. This has been classified as a TO galaxy in the optical spectroscopic analysis and is one of the three neighbours (for which XMM observations are available, see Table 4) having an active nucleus based on optical spectroscopy. Additional information on the nature of our sources can be extracted from the hardness ratios. Two sources NGC526-N2 and NGC1358-N2 have hardness ratios suggesting absorption $N_H \approx 10^{22} \text{ cm}^{-2}$, consistent with the presence of a moderately obscured active nucleus. Both these galaxies present no optical emission lines and thus are classified as normal, based on their optical spectra. In other words, the lack of optical emission lines from the nucleus of these objects could be a result of obscuration. In addition, we should mention here that in the group of objects with an X-ray observation, all galaxies classified as “normal” through optical spectroscopy present an X-ray detection, possibly also indicating the presence of nuclear activity. In contrast, all SFG galaxies except one in the X-ray subsample do not show an X-ray detection.

We should note here that unobscured low accretion rate Sy2 objects and/or low luminosity AGN, where the NLR cannot be detected by means of optical spectroscopy, or even X-ray binaries, may account for the X-ray detection of unobscured “normal” galaxies. This analysis therefore implies that the total fraction of neighbours of AGN that show activity, based on optical spectroscopy, is at least 70% and possibly quite higher. This matter will be fully addressed in future work.

4. Discussion & Conclusions

Based on optical spectroscopy, we have found that the large majority ($> 70\%$) of close neighbours of AGN (being Sy1 or Sy2) show activity, mostly enhanced star-formation but AGN as well. Furthermore, the close neighbours of Sy1 galaxies, being SFG or AGN, are less ionized and thus seem to be a different, more evolved, population than those of Sy2s.

In addition, our X-ray analysis of a subsample of neighbours with public XMM observations showed that the neighbours which are classified as “normal” based on optical spectroscopy, might have an active core, since all of them are X-ray detected, while two out of five appear to have a moderately obscured active nucleus. On the contrary, the pure star forming neighbours do not show any X-ray emission, down to the flux limit of the available observations. From both, optical spectroscopy and X-ray observations, it becomes clear that the fraction of neighbours, within $100 h^{-1} \text{ Mpc}$, of AGN or BIRG that are active is $> 70\%$ and possibly much higher.

Since the physical properties of the neighbours should be reflected on the state of the central AGN galaxy, we argue that these results are in the same direction as those of our previous papers (Koulouridis et al 2006a,b), supporting an evolutionary sequence of galaxy activity, induced by interactions, the main path of which starts from inactivity and then follows the sequence of starburst, Sy2 and finally Sy1 phase.

We now attempt to interpret our present results within the above evolutionary scheme. Something that is nowadays undisputed is the role of interactions in the creation of a starburst. Molecular clouds are being forced towards the galactic center, become compressed and light up the galaxy as a starburst. Despite the fact that the exact mechanism is still unknown, in the local universe an accretion rate of $\sim 0.001 - 0.1 M_\odot/\text{yr}$ is needed in order to fuel the black hole. Theoretically this can only be achieved by means of a non axisymmetric perturbation

which induces mass inflow. Such perturbations are provided either by bars or by interactions. Whichever the mechanism may be, the result is the feeding of the black hole and the activation of the AGN phase, maybe $\sim 0.5\text{Gyr}$ after the initial interaction took place. An interaction certainly predicts such a delay, since after the material has piled up around the inner Linblad resonance, producing the Starburst, it can be channeled towards the nucleus by loosing significant amounts of angular momentum, a process which is not instantaneous. Therefore, a delay should exist between the pure starforming and AGN phase, where active nucleus and circumnuclear starburst coexist. In this initial phase, the nucleus is heavily obscured by the still starforming molecular clouds and it can be observed as a transition stage of composite Sy2-starburst objects.

The most probable manner for the AGN to dominate is to eliminate the starburst, possibly by the AGN outflows or by radiation pressure. Outflows from the core have enough energy to dissipate the material around it and thus suffocate star formation (e.g. Krongold et al. 2007, 2009; Blustin et al. 2008; Hopkins & Elvis 2010; Novak, Ostriker & Ciotti 2011; Cano-Díaz et al. 2012; Zubovas & King 2012).

This could also take some time and as the starburst fades, the Seyfert 2 state starts dominating, to be followed at the end by a totally unobscured Sy1 state, possibly $\sim 1\text{Gyr}$ after the initial interaction.

The time needed for type 1 activity to appear should be larger than the timescale for an unbound companion to escape from the close environment, or comparable to the timescale needed for an evolved merger ($\sim 1\text{Gyr}$, see Krongold et al. 2002).

Alternatively, there is a possibility that the neighbours of Sy1 galaxies are systematically more massive and that their older stellar population is due to downsizing, i.e. more massive galaxies have evolved earlier, while less massive ones exhibit more recent starformation and thus younger stellar population. However, there is no obvious explanation on why more massive galaxies should be located preferentially near Sy1 galaxies and not Sy2. The combination of both downsizing and the interaction driven sequence, as presented previously, can also be at work.

From our point of view, in an ever evolving universe an evolutionary scheme, is more probable than the original unification paradigm which proposes a rather static view of AGN. Of course, orientation could and should also play a role between the obscured Sy2 and Sy1 phase, when the relaxing obscuring material forms a toroidal structure.

There are still many unresolved issues and caveats concerning these suggestions, since the evolutionary sequence is not unique and should also depend on the geometry, the density and other factors of the obscuring and the accreting material, as well as on the mass of the host galaxy and its black hole.

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Table 1. The sample of Sy1 galaxies and their neighbours¹

<i>NAME</i>	<i>RA</i> <i>J2000.0</i>	<i>DEC</i> <i>J2000.0</i>	<i>O</i> _{MAPS} <i>integrated</i>	<i>z</i>
NGC 863	02 14 33.5	−00 46 00	14.58	0.0270
neighbour 1	02 14 29.3	−00 46 05	18.25	0.0270
MRK 1400	02 20 13.7	+08 12 20	17.07	0.0293
neighbour 1	02 19 59.8	+08 10 45	17.25	0.0284
NGC 1019	02 38 27.4	+01 54 28	15.02	0.0242
neighbour 2	02 38 25.4	+01 58 07	16.28	0.0203
NGC 1194	03 03 49.1	−01 06 13	15.38	0.0134
neighbour 1	03 03 41.2	−01 04 25	16.99	0.0140
neighbour 4	03 04 12.5	−01 11 34	15.75	0.0130
1H 1142−178	11 45 40.4	−18 27 16	16.82	0.0329
neighbour 1	11 45 40.9	−18 27 36	18.01	0.0322
neighbour 2	11 45 38.8	−18 29 19	18.45	0.0333
MRK 699	16 23 45.8	+41 04 57	17.21	0.0342
neighbour 1	16 23 40.4	+41 06 16	17.59	0.0334
NGC 7469	23 03 15.5	+08 52 26	14.48	0.0162
neighbour 1	23 03 18.0	+08 53 37	15.58	0.0156
NGC 526A ²	01 23 54.5	−35 03 56	15.69 ³	0.0191
neighbour 1	01 23 57.1	−35 04 09	15.80 ³	0.0188
neighbour 2	01 23 58.1	−35 06 54	15.68 ³	0.0189
neighbour 3	01 24 09.5	−35 05 42	16.37 ³	0.0185
neighbour 4	01 23 59.2	−35 07 38	16.04 ³	0.0185
NGC 5548	14 17 59.5	+25 08 12	14.18	0.0172
neighbour 1	14 17 33.9	+25 06 52	17.16	0.0172
NGC 6104	16 16 30.7	+35 42 29	15.11	0.0279
neighbour 1	16 16 49.9	+35 42 07	16.44	0.0264

⁽¹⁾ within a projected distance of 100 h^{-1} kpc⁽²⁾ Region Not Covered by MAPS Catalog⁽³⁾ Calculated from O_{USNO} , using relation: $O_{\text{MAPS}} = 14.61(\pm 1.25) + 0.11(\pm 0.11)O_{\text{USNO}}$, derived from Véron-Cetty et al. (2004) Table 2.

Table 2. The sample of Sy2 galaxies and their neighbours¹

<i>NAME</i>	<i>RA</i> <i>J2000.0</i>	<i>DEC</i> <i>J2000.0</i>	<i>O</i> _{MAPS} <i>integrated</i>	<i>z</i>
ESO 545-G013	02 24 40.5	-19 08 31	14.41	0.0338
neighbour 1	02 24 50.9	-19 08 03	16.19	0.0340
NGC 3786	11 39 42.5	+31 54 33	13.88	0.0091
neighbour 1	11 39 44.6	+31 55 52	13.53	0.0085
UGC 12138	22 40 17.0	+08 03 14	15.93	0.0250
neighbour 1	22 40 11.0	+07 59 59	18.77	0.0236
UGC 7064	12 04 43.3	+31 10 38	15.11	0.0250
neighbour 1(2) ²	12 04 45.6	+31 11 27	16.68	0.0236
neighbour 1	12 04 45.2	+31 11 33	16.33	0.0244
neighbour 2	12 04 45.1	+31 09 34	16.33	0.0261
IRAS 00160-0719	00 18 35.9	-07 02 56	15.73	0.0187
neighbour 1	00 18 33.3	-06 58 54	17.80	0.0173
ESO 417-G06	02 56 21.5	-32 11 08	15.54	0.0163
neighbour 1	02 56 40.5	-32 11 04	17.43	0.0163
NGC 1241	03 11 14.6	-08 55 20	13.56	0.0135
neighbour 1	03 11 19.3	-08 54 09	15.41	0.0125
NGC 1320	03 24 48.7	-03 02 32	14.59	0.0090
neighbour 1	03 24 48.6	-03 00 56	15.07	0.0095
MRK 612	03 30 40.9	-03 08 16	15.78	0.0207
neighbour 1	03 30 42.3	-03 09 49	16.13	0.0205
NGC 1358	03 33 39.7	-05 05 22	13.98	0.0134
neighbour 2	03 33 23.5	-04 59 55	14.95	0.0131
IC 4553	15 34 57.1	+23 30 16	14.43	0.0181
neighbour 1	15 34 57.3	+23 30 05	15.68	0.0190
NGC 7672	23 27 31.4	+12 23 07	15.23	0.0134
neighbour 1	23 27 19.3	+12 28 03	14.67	0.0138
NGC 7682	23 29 03.9	+03 32 00	14.88	0.0171
neighbour 1	23 28 46.6	+03 30 41	14.64	0.0171
NGC 7743	23 44 21.1	+09 56 03	12.16	0.0044
neighbour 3	23 44 05.5	+10 03 26	16.95	0.0054

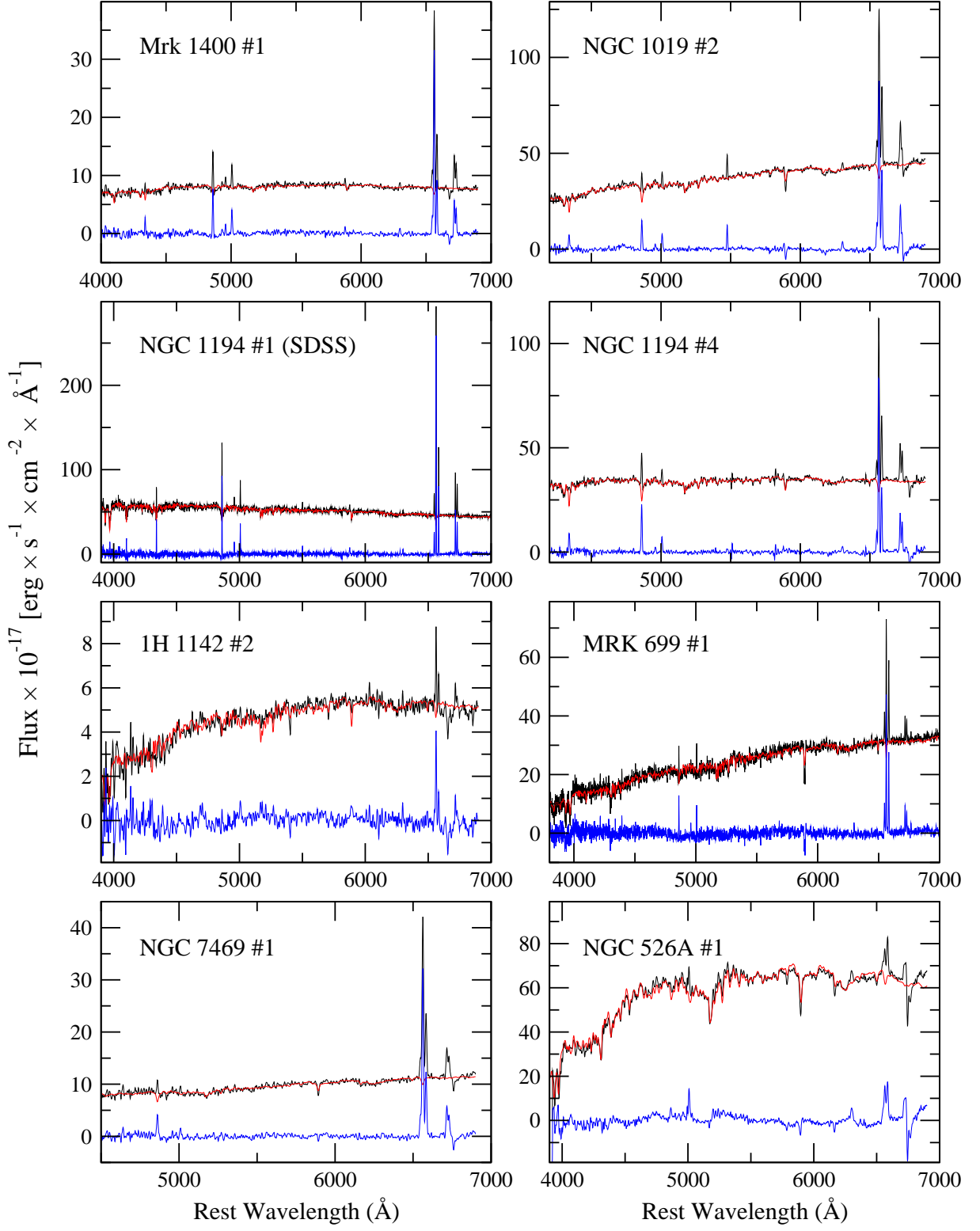
⁽¹⁾ within a projected distance of $100 h^{-1}$ kpcs⁽²⁾ In Koulouridis et al. 2006a neighbour 1 was an unresolved merging galaxy. In this paper we were able to obtain two distinct spectra for each nucleus.

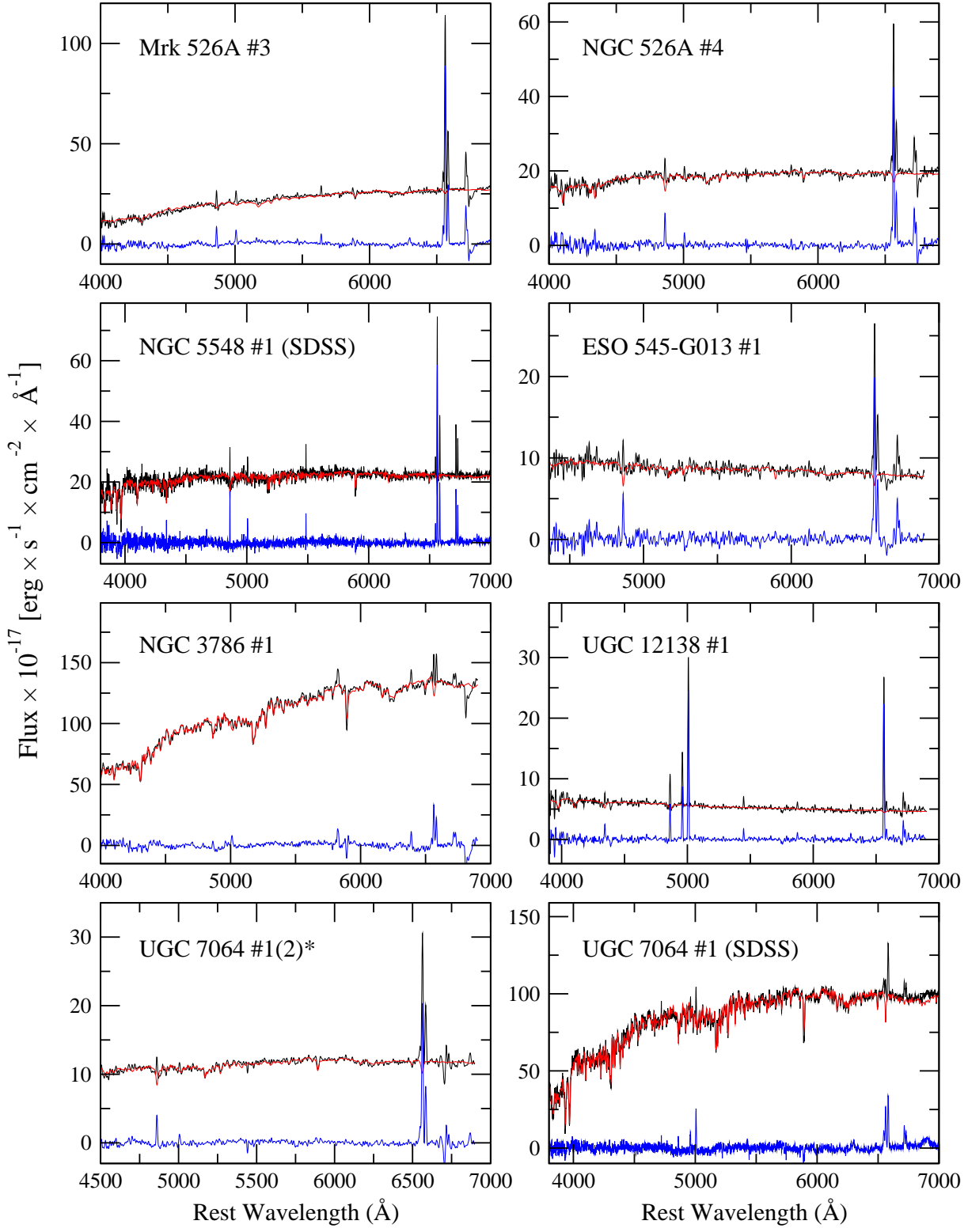
Table 3. Observational data, emission line ratios and classification.

<i>NAME</i>	Neigh. No	<i>U.T. date</i> (dd/mm/yy)	<i>start U.T.</i>	<i>exp. time</i> (sec)	[OIII]/H β	[NII]/H α	[SII]/H α	<i>Stasińska</i> ¹	BPT ²
Sy1 galaxies									
NGC 863	N1	SDSS	-	-	-	-	-	normal	normal
MRK 1400	N1	06/10/07	07:31	4800	0.55±0.02	0.31±0.01	0.35±0.01	SFG	SFG
NGC 1019	N2	21/10/06	08:25	4800	0.54±0.01	0.46±0.01	0.32±0.01	TO	TO
NGC 1194	N1	SDSS	-	-	0.37±0.01	0.31±0.01	0.35±0.01	SFG	SFG
NGC 1194	N4	25/10/06	07:56	5400	0.33±0.01	0.38±0.01	0.36±0.01	SFG	SFG
1H 1142–178	N1	19/05/07	04:29	3000	-	-	-	normal	normal
1H 1142–178	N2	21/05/07	04:16	6000	0.83±2.54	0.35±0.03	0.57±0.06	SFG	SFG
MRK 699	N1	18/05/07	10:27	2100	0.64±0.12	0.60±0.06	0.67±0.05	TO	TO
NGC 7469	N1	01/12/06	03:07	3600	0.30±0.05	0.37±0.01	0.29±0.01	SFG	SFG
NGC 526A	N1	08/10/07	06:39	2400	3.60±0.37	1.37±0.19	1.32±0.18	AGN	AGN
NGC 526A	N2	08/10/07	08:39	1500	-	-	-	normal	normal
NGC 526A	N3	08/10/07	09:34	3600	0.57±0.06	0.35±0.01	0.35±0.02	SFG	SFG
NGC 526A	N4	08/10/07	07:33	3600	0.34±0.02	0.34±0.01	0.38±0.01	SFG	SFG
NGC 5548	N1	SDSS	-	-	0.50±0.05	0.36±0.01	0.52±0.01	SFG	SFG
NGC 6104	N1	18/05/07	09:37	1800	-	-	-	normal	normal
Sy2 galaxies									
ESO 545-G013	N1	01/12/06	05:13	3600	-	0.37±0.01	0.37±0.02	SFG	-
NGC 3786	N1	06/03/06	06:34	3600	1.08±0.06	0.71±0.02	0.57±0.02	AGN	TO
UGC 12138	N1	08/10/07	02:49	3600	4.48±0.11	0.07±0.01	0.18±0.01	SFG	SFG
UGC 7064	N1(2)	18/05/07	07:11	4200	0.25±0.02	0.38±0.01	0.15±0.01	SFG	SFG
UGC 7064	N1	SDSS	-	-	3.55±0.34	1.34±0.4	0.83±0.03	AGN	AGN
UGC 7064	N2	06/03/06	08:40	2100	0.74±0.05	0.56±0.02	0.30±0.02	TO	TO
IRAS 00160–0719	N1	06/10/07	-	-	0.97±0.02	0.25±0.01	0.44±0.01	SFG	SFG
ESO 417-G06	N1	06/10/07	11:08	4200	1.29±0.01	0.21±0.01	0.29±0.01	SFG	SFG
NGC 1241	N1	30/11/06	08:00	3600	1.02±0.04	0.34±0.01	0.35±0.01	SFG	SFG
NGC 1320	N1	25/10/06	09:38	3600	-	-	-	normal	normal
MRK 612	N1	29/11/06	09:44	3600	-	-	-	normal	normal
NGC 1358	N2	21/10/06	11:08	3600	-	-	-	normal	normal
IC 4553	-	19/05/07	09:14	5400	-	-	-	merger	-
NGC 7672	N1	21/10/06	05:51	3600	-	-	-	normal	normal
NGC 7682	N1	25/10/06	06:42	3600	1.25±0.01	0.45±0.01	0.27±0.01	TO	TO
NGC 7743	N3	20/10/06	07:00	5400	2.27±0.03	0.07±0.01	0.24±0.01	SFG	SFG

⁽¹⁾ Classification based on Stasińska et al. (2006)⁽²⁾ Classification based on the BPT diagrams (Baldwin, Phillips & Terlevich 1981)**Table 4.** XMM observations.

<i>Name</i>	<i>Neigh. No</i>	<i>2XMM ID</i>	<i>Opt. Class</i>	<i>logL_X</i> (0.2–12 keV) (erg s ⁻¹)	<i>Flux</i> (0.2–12 keV) (erg cm ⁻² s ⁻¹)	<i>X/O offset</i> (arcmin)	<i>HR</i>
NGC1194	N1	-	SFG	< 39.59	< 7.3 × 10 ⁻¹⁵	-	-
NGC1194	N4	-	SFG	< 39.72	< 1.1 × 10 ⁻¹⁴	-	-
NGC526A	N1	J012357.0-350410	AGN	40.46	3.3 × 10 ⁻¹⁴	0.023	-0.28 ± 0.09
NGC526A	N2	J012358.1-350653	Normal	40.75	5.9 × 10 ⁻¹⁴	0.008	0.05 ± 0.1
NGC526A	N3	-	SFG	<39.65	< 4.7 × 10 ⁻¹⁵	-	-
NGC526A	N4	J012359.0-350741	SFG	39.95	9.4 × 10 ⁻¹⁵	0.035	-0.61 ± 0.29
UGC12138	N1	-	SFG	<40.63	< 2.8 × 10 ⁻¹⁴	-	-
NGC1320	N1	J032448.6-030057	Normal	39.46	1.2 × 10 ⁻¹⁴	0.020	-0.38 ± 0.17
MRK612	N1	J033042.5-030949	Normal	39.59	3.4 × 10 ⁻¹⁵	0.060	-0.67 ± 0.24
NGC1358	N2	J033323.3-045953	Normal	40.19	3.8 × 10 ⁻¹⁴	0.044	0.05 ± 0.3
NGC7682	N1	J232846.7+033041	TO	42.04	1.30 × 10 ⁻¹²	0.026	-0.32 ± 0.02
NGC7743	N3	-	SFG	<39.44	3.4 × 10 ⁻¹⁴	-	-
NGC3786	N1	J113944.3+315547	TO	39.73	2.7 × 10 ⁻¹⁴	0.08	-0.46 ± 0.30





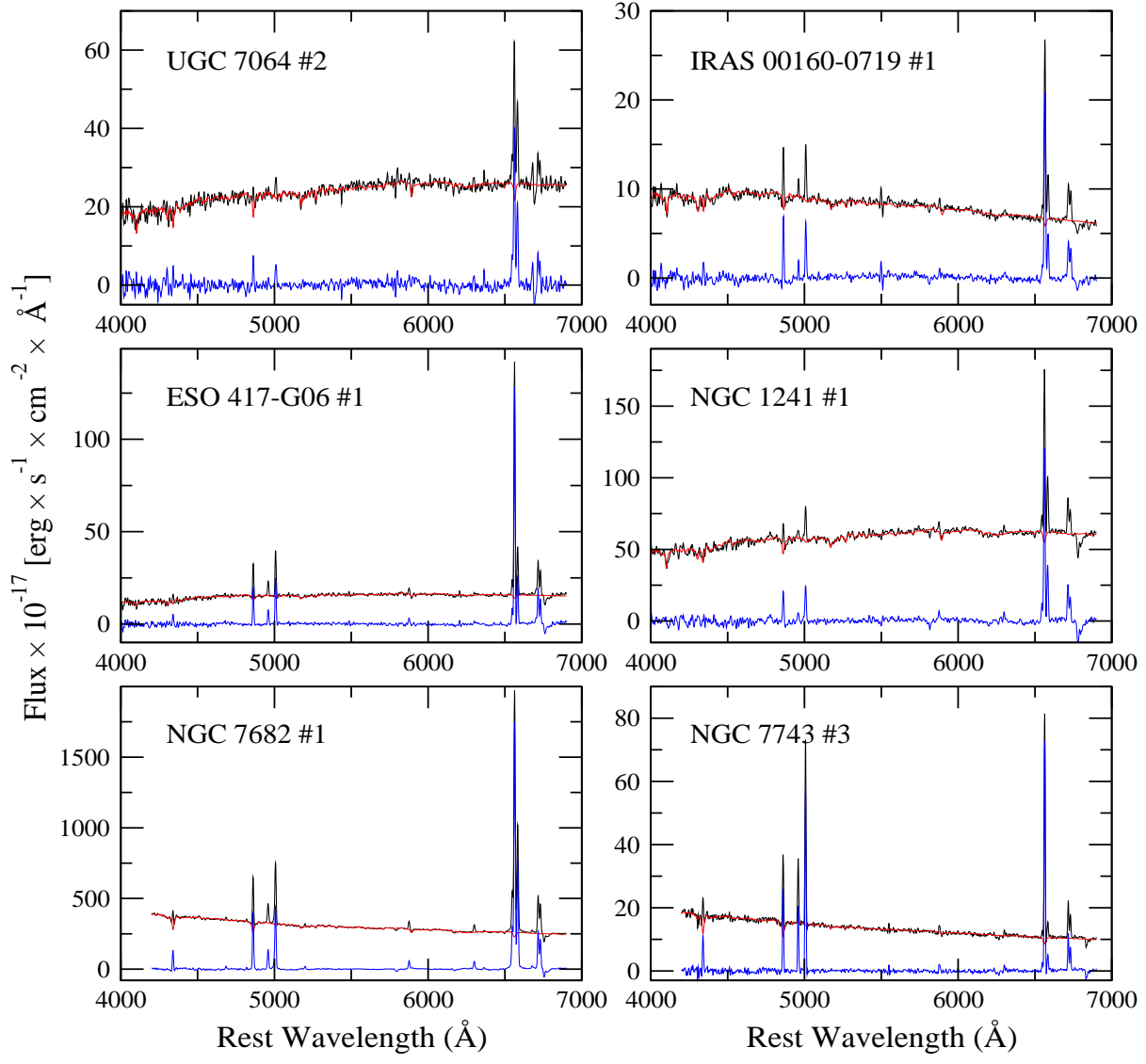


Fig. 3. Spectra of the neighbours of AGN galaxies, listed in Tables 1 & 2